Process Improvement and Layout Optimization in a Forging Company

Andrea Bogert, William Edwards, Farzad Jalali and Faisal Aqlan*
Master of Manufacturing Management (MMM) Program
Penn State Erie, The Behrend College
Erie, PA 16509, USA
*FUA11@psu.edu

Abstract

Optimization of production layout in manufacturing can be achieved through process improvement methods. Lean manufacturing is a common process improvement method that has been implemented by many originations and proven successful outcomes. Lean manufacturing is used to identify, analyze, and optimize internal material flow. In this paper, we discuss the implementation of Lean process improvement to optimize production flow in forging industry. The study is conducted in a custom steel forge shop that utilizes 2,000 ton open forge dies, 11 heat treat furnaces, and 5 quenching stations to manufacture large metal parts for oil and gas, military, mining, automotive, and aerospace industries. Currently, the shop is facing issues in the efficiency of the product flow and plant layout. Three production areas of interest are considered while re-evaluating the plant layout. Proposed changes are analyzed based on distance and proximity importance. The layout alternatives are compared based on Net Present Value (NPV) and payback period. The final results show the proposed changes will reduce product travel time as well as relieve bottlenecks in the shipping bay.

Keywords
Process improvement, Lean manufacturing, forging industry, layout optimization.

1. Introduction

In a manufacturing environment, the plant layout can have a significant impact on the overall efficiency of a company. A plant layout is the design for a floor plan that arranges the equipment in an order and location that minimizes time and cost. There are four main types of production layouts: product layout, process layout, fixed position layout, and cellular layout.

A product layout is generally geared towards manufacturing processes that aim to assemble or produce large quantities of products in a short period of time. The machinery and equipment are placed sequentially so to produce the product in a line of alterations. The benefit of this layout is that there are no buffer storage stations within the line which increases the output of products, there is a smooth and efficient direct flow of material, and the production of the parts is quick due to the lack of set up time and adjustment of machinery. The disadvantages that accompany this layout is the lack of flexibility, a high investment in equipment, and the fact that a single machine failure in the production line causes the entire product flow to stop.

A process layout is a layout that groups similar machines and services together. In this layout, products flow from one station to the next, using different machines at each station depending on the product. This layout is designed to produce low quantities of complex products. The benefit of this layout includes high flexibility and the ability to change production lines due to unforeseen difficulties like breakdowns by routing the product to a different machine in the station. Some disadvantages include large amounts of material handling, production routing difficulties, and increased amounts of work-in-process (WIP).

In fixed position layout, equipment and supplies are brought to the site where the product is assembled, rather than the product being moved through an assembly line or set of assembly stations. This layout is used to assemble products that are too large, bulky, or fragile to safely or effectively move to a location for completion.

Cellular layout involves grouping the machines based on the process requirements for a set of similar items (part families) that require similar processing. The groups are called cells and the technique for grouping is known as Group Technology (GT). The main advantages of cellular layout include increased flexibility, faster processing times, cross-trained workers, less WIP, and reduced set up time.

In forging industry, production layout is an important factor that affects the company's efficiency. Forging is manufacturing process in which metal is pressed, pounded or squeezed under great pressure into high strength parts that are known as forgings. The forging process is usually perform by preheating the metal to a desired temperature before it is worked. The forged parts are usually stronger than those manufactured by any other metalworking process. Forging shops should have efficient production layout to eliminate obstructions in material flow and improve productivity. In this paper, we discuss the case of using Lean process improvement techniques to optimize production layout in a forging shop. Multiple layout alternative are evaluated based on distance, proximity importance, and cost.

2. Related Literature

The use of process improvement methodologies in manufacturing environments have been discussed by multiple authors. Aqlan (2018) presented a study on implementing Lean six sigma process improvement in casting industry. Several process improvement projects were identified and five projects were selected to improve the productivity of the foundry.

Several studies in the literature have discussed optimization of production layout for different reasons. For instance, Thottungal (2008) have created and Automated Layout Design Program (ALDEP) to simulate the best form of layout that is required. The study argues that the optimal layout strategy for a company is a mix of product line layout and process layout. If the work stations are not located in such a manner as to facilitate straight line flow throughout the facility, the back and forth movement of the product will add a significant amount to the time and cost. A relationship table was used to determine the value of movements between various departments.

Vishnu et al. (2017) have conducted a study to improve the plant efficiency and machine utilization by finding the most efficient arrangement of each workstation. The study was performed by Computerized Relative Allocation of Facility technique. This technique allows to figure out which station was or was not in line with production process. For this process, each department was measured by its area and its centroids were identified by different colors.

As discussed in Hung and Maleki (2013), Group Technology (GT) technique can result in shorter development and production lead time. However, GT implementation could be challenging based on the correct grouping of parts into families. Some coding system such as hierarchical, chained-type and hybrid structures are needed to achieve this process. Even though, GT is often appropriate in metal machining operation, still, the coding systems may not be universally applicable. The authors presented a case for applying GT in forging industry.

Simulation and optimization methods can also be used to optimize production layouts. Aqlan et al. (2014) discussed the use of simulation and optimization techniques to improve production layout in server manufacturing by consolidating production line and changing product layout to process layout.

In this paper, we discuss the optimization of production layout in forging industry utilizing Lean manufacturing techniques. By optimizing the forging layout, the energy required and process time can be reduced. If any heat-treatment of work pieces is required, by facilitating a straight line flow the overwork can minimized. By optimizing the individual production steps a partial improvement can be achieved. In this study, we perform data analysis and map the process flow through the entire manufacturing layout. Moreover, Total Closeness Rating (TCR) is practiced. This process is performed by actual measurements of the plant layout and processing steps.

3. System Description and Problem Definition

The forging company considered in this study is an Open Die Forging shop that provides its customer with custom forgings. The company can provide its customers with heat treated, destructive and non-destructive tested, and rough machined forgings. The 2,000 ton Open Die Press has the capability to forge an array of forgings such as bar, rings, sleeves, disks, and step shafts. The company has 11 furnaces to heat treat forging to meet specified properties and 5 quench tanks (2 water and 3 oil); to help achieve the required mechanical properties. The Destructive Test Lab can perform an array of mechanical tests such as tensile, impacts, macrostructure, and microstructure. Simulated heat treatments can also be performed on test samples to provide capability testing. The company has the ability to rough machine forgings on its many vertical turret lathes, turret lathes, engine lathes, and horizontal mill. Once turned, non-destructive testing s performed on the forgings such as ultrasonic, magnetic particle, and liquid penetrant inspection tests. The company works on product that is supplied to many different product sectors such as Power Generation, Oil & Gas, Gearing, Military, Mining, Automotive, and Aerospace. The current plant layout can be seen in Figure 1.

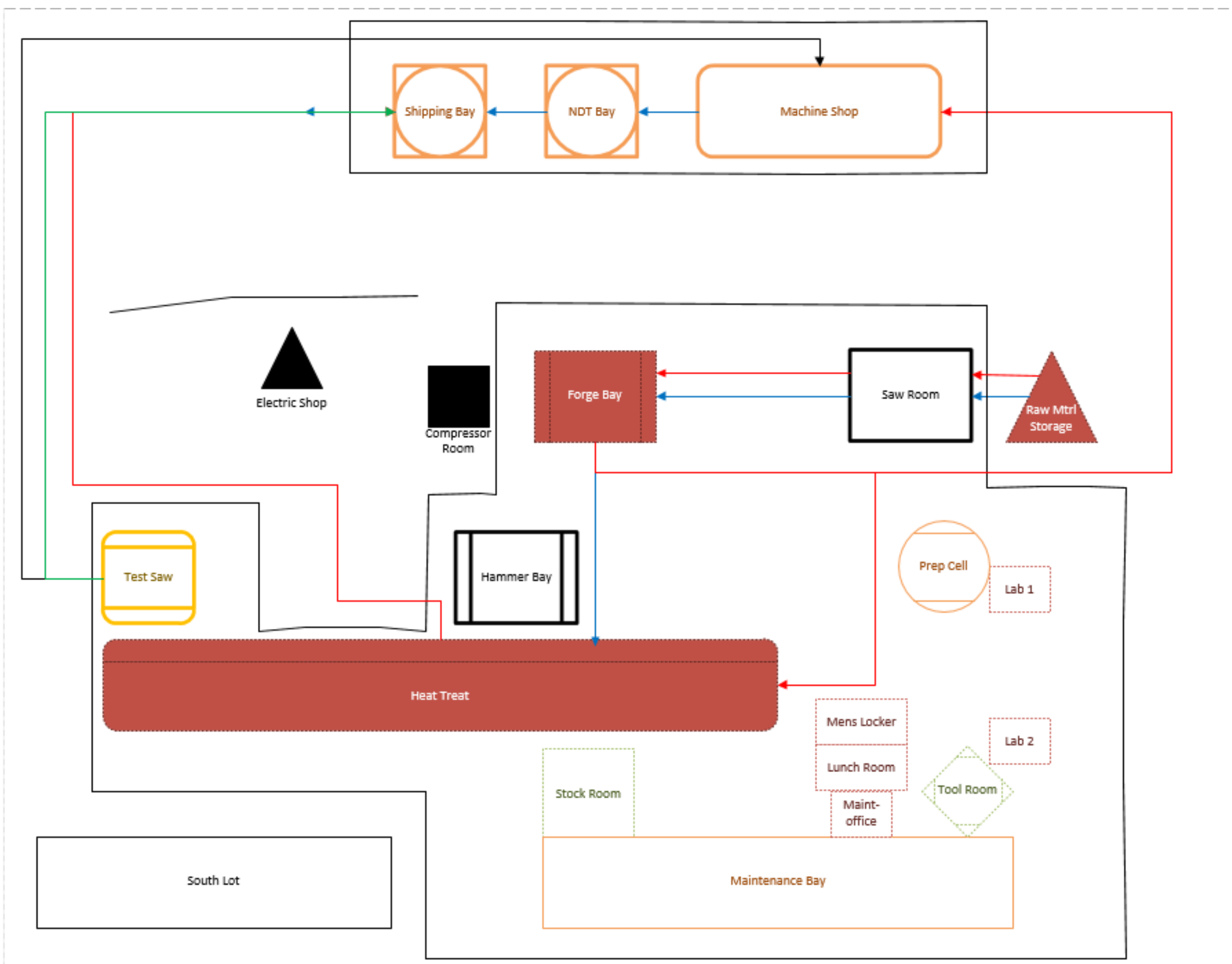

Figure 1. Current plant layout

The process of making a forging is largely dependent on what the customer requires the forgings to be capable of, but the basic operations follow a set normal flow. The basic process flow for product through the plant can be seen in Figure 2. The forging process always starts with the raw material coming from the raw material storage yard. Depending on the size of the stock and the configuration of the forging the stock may need to be sawed to size prior to forging. Once the material is forged according to its forging practice, the material must be slow cooled. Once the material has reached room temperature, the forging will be sent to the machine shop to get a skim cut done prior to heat treatment. If the forging does not require machining prior to heat treatment the skim cut operation will be skipped and then sent directly to Heat Treat. Once the forging is properly heat treated, a preliminary Brinell check is done to ensure the forging will meet the required mechanical properties. In order for the preliminary Brinell check to be conducted, the forging must be transported across the train track to the shipping department where the stationary King Brinell drill press is located. If the customer has ordered an as-forged product without testing this is the end of the process and the forging can be shipped. If testing is required the forging will be sent back across the tracks to the test saw area to have the mechanical test coupons cut out of the forging. The test samples are then carried to the Destructive Test lab where they are prepped and tested. Once all the mechanical testing is completed and has passed the forging is transported back across the tracks to the machine shop to get its final rough turn. After being machined the forging can be non-destructively tested and final inspection can be completed. Once everything is done the forging is ready to be shipped to the customer.

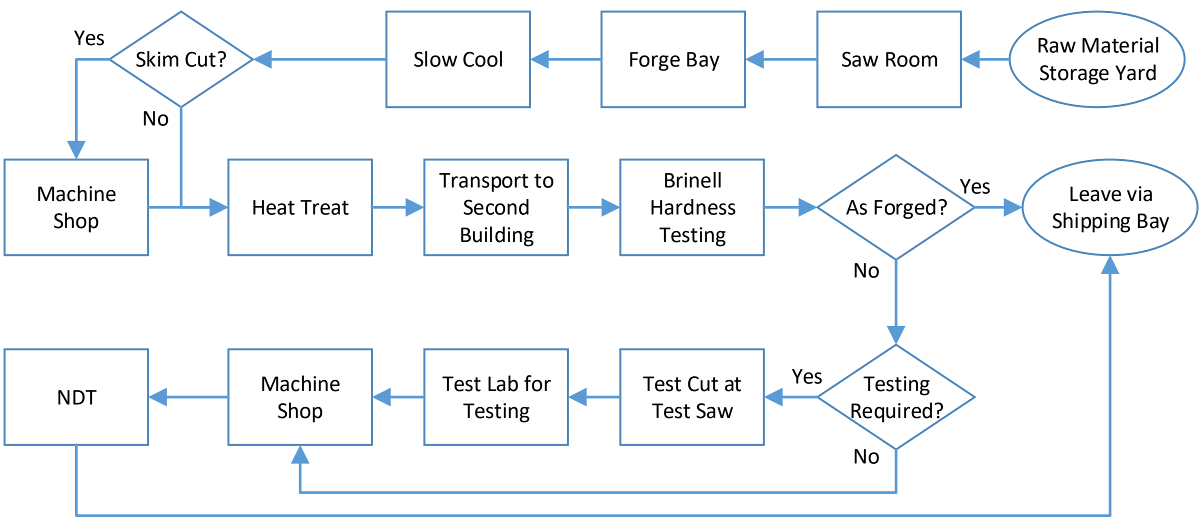

Figure 1. Current process flow

In the current process flow, there are a few departments that are inconveniently further apart then what would be ideal based upon the process flow. The goal is to explore options to maximize the efficiency of the plant layout in respect to the process flow. To meet this goal, we will look at the distance the forging will travel between each department and analyze the financial cost associated with the layout changes to determine what solution will provide the best and most financially suitable solution.

There are some constraints with the current layout that cannot be changed. These constraints include:

- There is no physical room to move or rearrange the raw material storage yard.
- The Forge Bay and entire Heat Treat area cannot be moved or rearranged.

The equipment in these two areas is very permanent and is strictly qualified and controlled for approved forging and heat treating practices. After our initial walk through of the plant layout, we see that there are two areas where improvements can be mad to reduce the amount of distance traveled by the forgings. Initially we see that the King Brinell Machine is not conveniently placed for preliminary Brinell checks, and the test saw area is also not placed very well in regards to the Destructive Test Lab and Machine Shop. These two areas are what our analysis will be concentrating on to determine if either area can be improved.

A Fishbone diagram was designed for breaking down the possible problems and grouping issues. In the Fishbone Diagram in Figure 3, six categories were used such as Measurements, Machine, Mankind, Environment, Materials, and Methods. Each category is followed by several subgrouping. Within the mankind group, human factors such as the number of employees at a given time, and the time is required for finding parts for every order were considered. The next group would be machining, in this group, lead time, cycle time, and the physical machinery were considered. Measurements, which is the center of the problem, in this group factors such as transportation, and distance between work stations were measured. Method, which is one of the major group, plant layout as a main factor was followed by two subgroups: waste of space, and separation of buildings. The second major factor is process layout. Within Materials grouping, machining and forging are the two major factors. The last category is Environment. In this group, three factors including weather, limited space, and outdoor storage were considered.

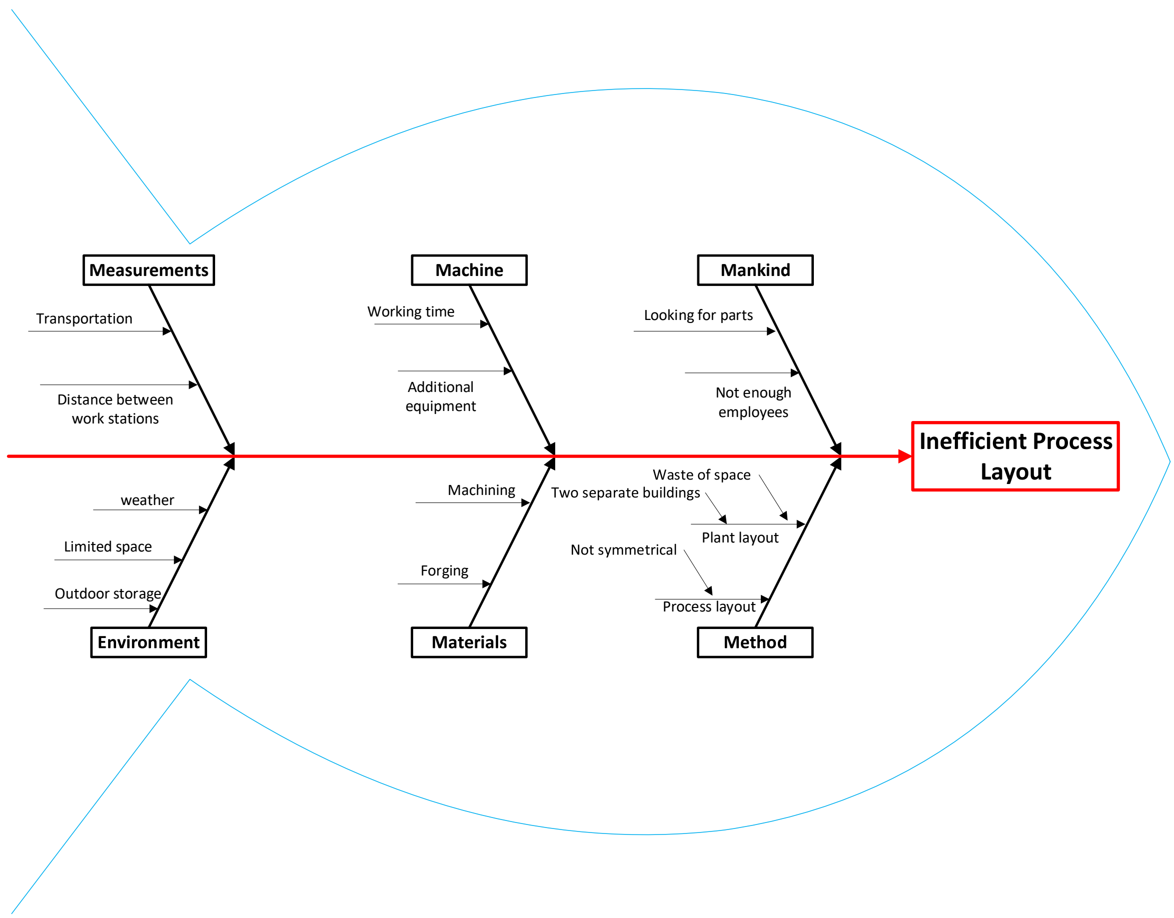

Figure 3. Fishbone diagram for the root cause analysis

4. Proposed Solutions

The proposed solutions were divided into three separate options. The first solution to improve efficiency in the plant layout was to add a new Brinell machine to the heat treatment station. This would eliminate the need for parts to leave the heat treatment station, enter the shipping bay, and then return to the heat treatment station. This option would reduce the cost of transportation of the parts as well as physical time saved that could be spent on other product in the shipping bay. The second option is very similar to the first, except that instead of a new Brinell machine, an Equotip machine is implemented in the heat treatment facility. This Equotip machine preforms similarly to the Brinell machine; however, it is cheaper and portable. The down side of implementing an Equotip machine is that it is less durable, less accurate, and will need replacement much sooner than a Brinell machine. The final option to increase plant layout efficiency is to relocate the three test saws to the maintenance bay. This would locate the test saws right next to the test lab, reducing travel time for test specimen.

The methodology for determining the distance was generalized with the use of a quadrant system for moves throughout the plant. The distance between each department was determined based upon the most common path of travel and the number of quadrants the material will pass through. The distances between the departments can be seen in Table 1. The relationship between the departments based on the process flow was also considered. The previous or next operation was required after an operation that department was given a "1" to show its importance. If the two departments had no relationship between them based upon the process flow the departments were given a "0". The importance chart for the current system can be seen in Table 2. In order to determine the distance a part would travel the distance matrix was multiplied by the importance matrix and the resulting Distance x Importance matrix is developed. All the numbers in the matrix were summed and then divided by two for the two repetitive side of the matrix. The final number is what we have determined to use as a baseline for the distance the material will travel though the manufacturing process. The smaller the number of the total sum the more efficient the plant layout is. The Distance x Importance matrix for the current system can be seen in Table 3. The financial calculations are calculated based upon a labor cost of $70 per hour. The initial investment costs for the plant layout options were determined by research and project cost estimations and provided by the Plant Engineer.

Table 1. Distance Between Departments Example for the Current Layout

	Stock Yard	Forge	Heat Treat	Saw Room	Test Saw	Destructive Lab	Machine Shop	NDT	Shipping	Maintenance Bay
Stock Yard	0	2	3	1	4	2	3	3	4	4
Forge	2	0	1	1	2	2	3	3	4	2
Heat Treat	3	1	0	2	1	1	4	4	5	1
Saw Room	1	1	2	0	3	1	2	2	3	3
Test Saw	4	2	1	3	0	2	3	3	2	2
Destructive Lab	2	2	1	1	2	0	3	3	4	2
Machine Shop	3	3	4	2	3	3	0	1	1	4
NDT	3	3	4	2	3	3	1	0	1	4
Shipping	4	4	5	3	2	4	1	1	0	4
Maintenance Bay	4	2	1	3	2	2	4	4	4	0

Table 2. Importance Between Departments Example for the Current Layout

	Stock Yard	Forge	Heat Treat	Saw Room	Test Saw	Destructive Lab	Machine Shop	NDT	Shipping	Maintenance Bay
Stock Yard	0	1	0	1	0	0	0	0	0	0
Forge	1	0	1	1	0	0	1	0	0	0
Heat Treat	0	1	0	1	1	0	0	0	1	0
Saw Room	1	1	1	0	1	0	1	0	0	0
Test Saw	0	0	1	1	0	1	1	0	0	0
Destructive Lab	0	0	0	0	1	0	1	0	0	0
Machine Shop	0	1	0	1	1	1	0	1	1	0
NDT	0	0	0	0	0	0	1	0	1	0
Shipping	0	0	1	0	0	0	1	1	0	0
Maintenance Bay	0	0	0	0	0	0	0	0	0	0

Table 3. Distance x Importance Matrix Example for the Current Layout

	Stock Yard	Forge	Heat Treat	Saw Room	Test Saw	Destructiv e Lab	Machine Shop	NDT	Shipping	Maintenance Bay
Stock Yard	0	2	0	1	0	0	0	0	0	0
Forge	2	0	1	1	0	0	3	0	0	0
Heat Treat	0	1	0	2	1	0	0	0	5	0
Saw Room	1	1	2	0	3	0	2	0	0	0
Test Saw	0	0	1	3	0	2	3	0	0	0
Destructive Lab	0	0	0	0	2	0	3	0	0	0
Machine Shop	0	3	0	2	3	3	0	1	1	0
NDT	0	0	0	0	0	0	1	0	1	0
Shipping	0	0	5	0	0	0	1	1	0	0
Maintenance Bay	0	0	0	0	0	0	0	0	0	0
Sum	3	7	9	9	9	5	13	2	7	0
Total Sum	32									

5. Results and Analysis

After developing distance x importance matrices for each of the proposed solutions, total sums were calculated for each layout. A matrix for adding a Brinell and an Equotip machine would result in the same summation; therefore, it was only calculated once. A matrix for moving the test saws was created as well as a matrix for both moving the test saw and adding a hardness machine in the heat treatment station. The total sums are shown in Table 4. It should be noted that a lower sum is an indication of a more efficient plant layout.

Table 4: Total sums for the four layout alternatives

Alternative	Total Sums
Current Layout	32
Adding Brinell/Equotip to heat treat	27
Moving test saws to maintenance	27
Both adding Brinell/Equotip and moving test saws	26

From the total distance x importance sums analysis, we can see that the most efficient option is to both add a Brinell/Equotip machine and move the test saws to maintenance. However, these options by themselves still showed a significant improvement when compared to the current layout. This information along with an NPV and payback period analysis will give us enough information for our final recommendation.

The initial investment values were determined by the Plant Engineer through research and plant renovation project experience. The projected cash savings was determined based upon two factors, the amount of time needed to move material and the amount of time that can be spent working on other product in the department. The amount of time needed to move the material was related back to the original grid developed to determine the distance between the departments. One "block" was determined to equal 5 minutes of travel time. The 5 minutes was then related to the cost of the work center at $70 per hour. With this relationship 5 minuets of travel time costs $5.83. The amount of time saved that can be spent working on other product was only used in the projected cash savings related to the Brinell machine. This value was calculated based upon the fact that on average it takes 1 employee 1 hour to process a preliminary Brinell on a forging. The processing time includes the prepping, testing, and reporting for the forging. The cost for the hour of work center is $70 per hour. Data provided by the company shows that on average 280 pieces are processed entirely in the plant each month. The total cost savings for Option 1 for adding the Brinell Machine and Option 2 adding the Equotip Machine total to $35,910 per month. The total cost savings for Option 3 moving the test saws totals to $16,310.

Table 5: NPV and Payback Analysis

	Option 1	**Option 2**	**Option 3**
Initial Investment	$ (25,000.00)	$ (9,000.00)	$ (375,000.00)
Projected Cash Savings			
Month 1	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 2	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 3	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 4	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 5	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 6	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 7	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 8	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 9	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 10	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 11	$ 35,910.00	$ 35,910.00	$ 16,310.00
Month 12	$ 35,910.00	$ 35,910.00	$ 16,310.00
Total Projected Savings:	$ 430,920.00	$ 430,920.00	$ 195,720.00
End of Year Replacements:	$ -	$ (9,000.00)	$ -
NPV (at 6%)	$ 276,063.84	$ 283,063.84	$ (238,259.51)
Payback Period (months)	0.70	0.25	22.99

6. Discussion and Recommendation

After reviewing the matrices and the financial data, it was found that both implementing a new Brinell hardness machine and Equotip machine have value. The cost savings that were found through the relocation of the test saws did not justify the decrease in distance. If the company is looking to implement a long term solution in the heat treatment station, it is recommend that they purchase a new Brinell machine. This will be a durable product that will last a significant amount of time without the need for major maintenance. It will produce a positive NPV of $276,063.84 after one year of investment and have a payback period of less than a month. If the company is looking to implement a more short term solution in the heat treatment station, we recommend that they purchase an Equotip machine. This will be significantly less expensive and will produce a higher NPV at $283,063.84 and a shorter payback period at only 8 days. However, we predict that the Equotip machine will need to be replaced annually, making it the more expensive solution after several years. Finally, we recommend that the company should avoid relocating the test saw equipment to the maintenance bay. The NPV after one year was significantly negative, at -238,259.51 and a payback period of 23 months. This solution requires too much initial investment to see the quick return on investment that the company is looking for.

References

Thottungal, A.P., Redesign the layout of a forging unit using discrete event simulation, *International Journal of Emerging Technology and Advanced Engineering*, vol. 3, no. 8, pp. 1-7, 2013.

Aqlan, F., Using Lean six sigma methodologies to improve operational performance in foundries, *International Journal of Lean Enterprise Research*, 2018, in press.

Vishu, N.A., Rakesh, P.R., and Surendran, A., Optimization of manufacturing plant layout design in SIFL using CRAFT, *International Journal of Current engineering and Scientific Research*, vol. 4, no. 7, pp. 45-48, 2017.

Aqlan, F., Lam, S.S., Ramakrishnan, S., An integrated simulation-optimization study for consolidating production lines in a configure-to-order environment, *International Journal of Production Economics*, vol. 148, pp. 51-61, 2014.

Hung, K.T., and Maleki, H., Applying group technology to the forging industry, *Production Planning and Control*, vol. 25, no. 2, pp. 134-148, 2013.

Biographies

Andrea Bogert, William Edwards and Farzad Jalali are master students in the Master of Manufacturing Management (MMM) program at Penn State Erie, The Behrend College.

Faisal Aqlan is currently an assistant professor of Industrial Engineering and Master of Manufacturing Management (MMM) at Penn State Behrend. He earned his Ph.D. in Industrial and Systems Engineering from the State University of New York at Binghamton in 2013. Aqlan has worked on industry projects with Innovation Associates Company and IBM Corporation. His work has resulted in both business value and intellectual property. He is a certified Lean Silver and Six Sigma Black Belt. He is a senior member of the Institute of Industrial and Systems Engineers (IISE) and currently serves as the president of IISE Logistics and Supply Chain Division, director of Young Professionals Group, and founding director of Modeling and Simulation Division. Aqlan is also a member of American Society for Quality (ASQ), Society of Manufacturing Engineers (SME), and Industrial Engineering and Operations Management (IEOM) Society. He has received numerous awards including the IBM Vice President award for innovation excellence, Penn State Behrend's School of Engineering Distinguished Award for Excellence in Research, and the Penn State Behrend's Council of Fellows Faculty Research Award. Aqlan is the Principal Investigator and Director of the NSF RET Site in Manufacturing Simulation and Automation at Penn State Behrend.